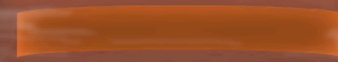
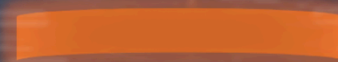


Status of 3ν oscillation parameters, circa 2013



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Outline:

- Intro: Data, notation, methodology
- **Global analysis 2013: Results**
- **Global analysis 2013: Interpretation**

Emphasis: octant, CP phase, hierarchy

Preprint to appear soon. Based on work by:
F. Capozzi, G.L. Fogli, E.L., A. Marrone, D. Montanino, A. Palazzo
Updates Fogli et al. arXiv:1205.5254 with recent 2013 data

Data sets: Notation

LBL Accelerators	=	K2K + T2K + MINOS
Solar	=	All Solar experiments
KL	=	KamLAND reactor expt
SBL Reactors	=	DChooz + RENO + DB
SK Atm	=	Super-K Atmospheric

3ν oscillation parameters: Notation

$\theta_{12}, \theta_{23}, \theta_{13}, \delta$	=	as in Particle Data Book
δ/π range	=	$[0, 2]$ (others prefer $[-1, +1]$)
δm^2	=	Δm^2_{21}
Δm^2	=	$(\Delta m^2_{31} + \Delta m^2_{32})/2$

Note: 1σ error on $\Delta m^2 \approx 0.07 \times 10^{-3} \text{ eV}^2 \approx \delta m^2$

(All parameters free to float in the global fit)

Combined analysis of data sets: Methodology

LBL Accelerator data are dominantly sensitive to $(\Delta m^2, \theta_{23}, \theta_{13})$. But, accurate constraints on these parameters do need $(\delta m^2, \theta_{12})$ input from Solar + KL to compute sub-dominant effects.

Moreover: CP-violation is a genuine 3ν effect, it would vanish in the approximation $\delta m^2 \sim 0$.

It makes sense to combine from the start: LBL Acc + Solar + KL. Note: Solar + KL data carry a preference (“hint”) for $\sin^2\theta_{13} \sim 0.02$

Combined analysis of data sets: Methodology

Sequence of combinations:

LBL Acc + Solar + KL

LBL Acc + Solar + KL + SBL Reactor

LBL Acc + Solar + KL + SBL Reactor + SK Atm.

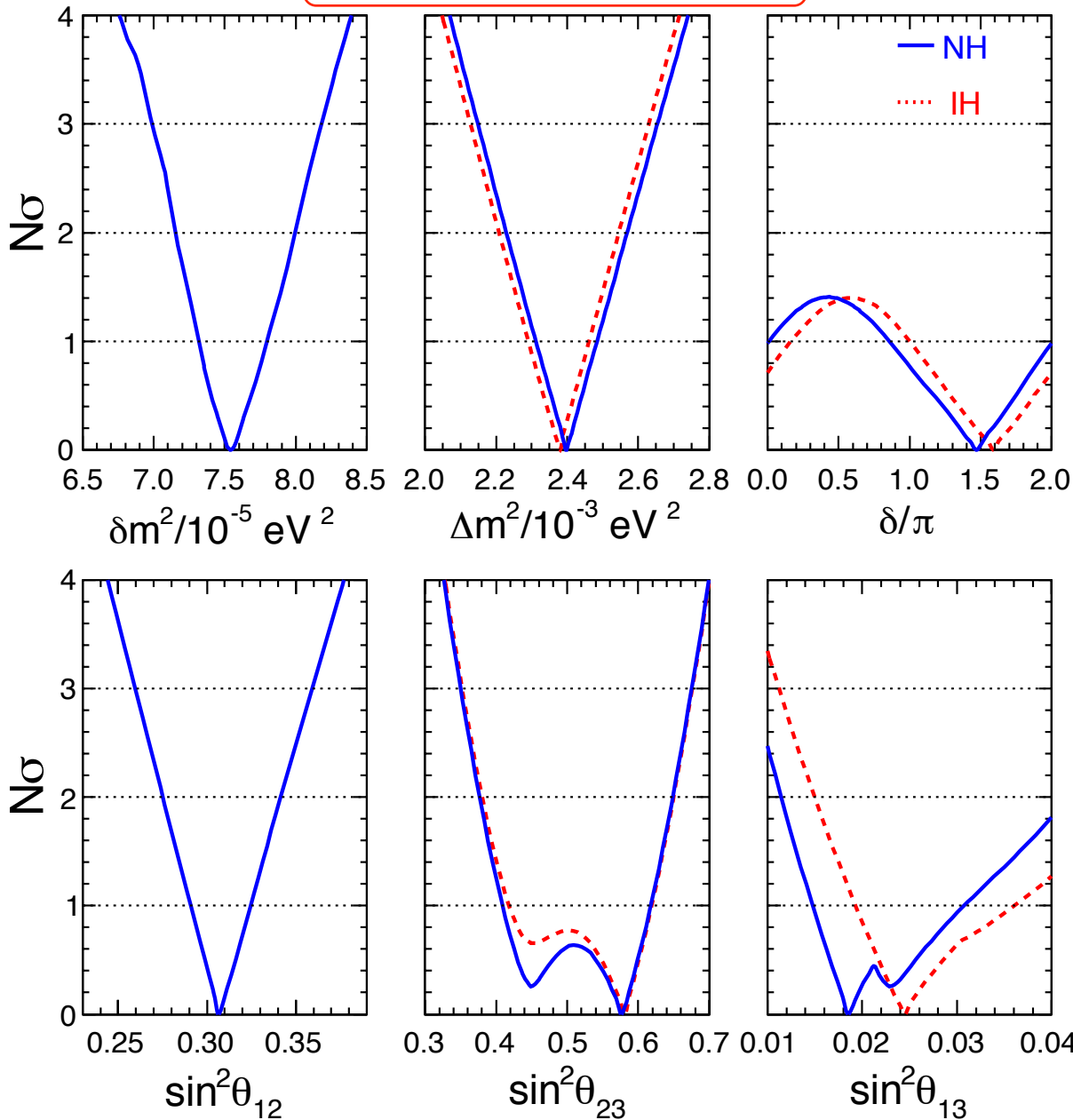
Figures: For any parameter(s) shown, the others are marginalized away. Contours are drawn at

$\Delta\chi^2 = 1, 4, 9 \rightarrow N\sigma = 1, 2, 3$ for 1 dof projections.

Numerical ranges not reported, will appear in preprint.

End of Intro. Results on single parameters \rightarrow

LBL Acc + Solar + KL

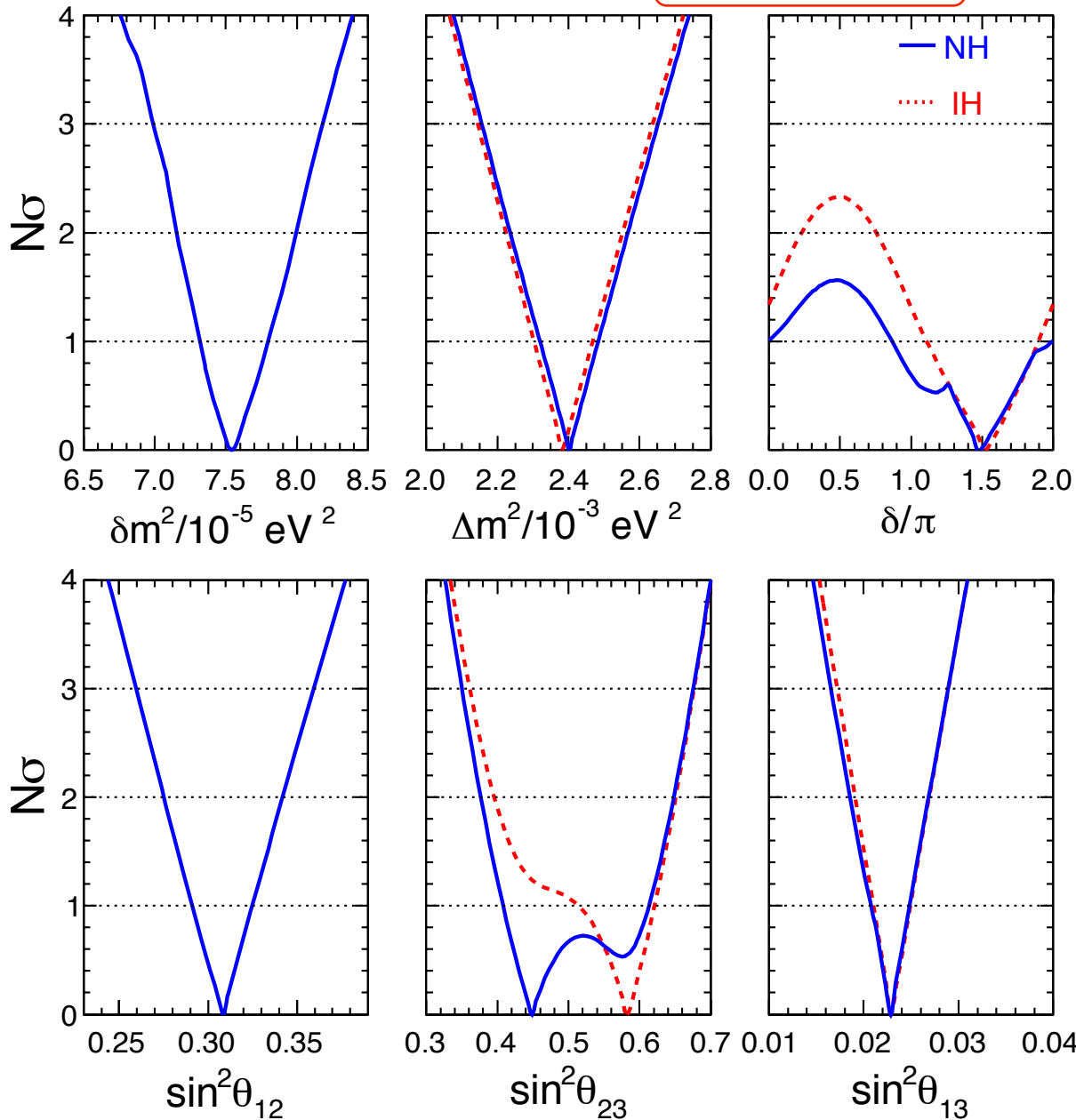


Upper and lower bound on all oscill. parameters but δ

Slight preference for $\delta \sim 1.5 \pi$

Slight preference for nonmaximal θ_{23} and for 2nd octant

LBL Acc + Solar + KL + **SBL Reactors**

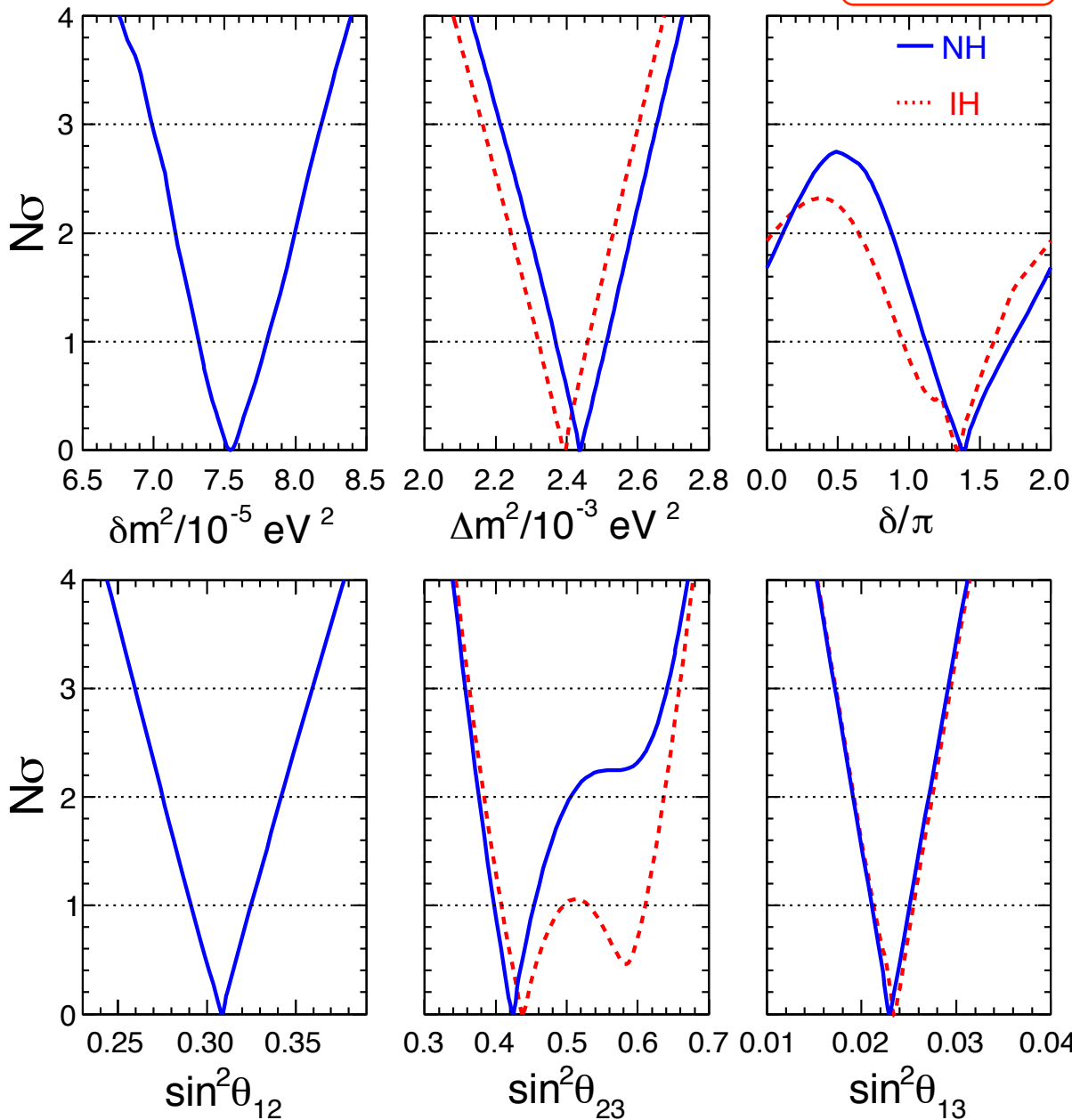


Strong θ_{13} bounds

Still a preference for $\delta \sim 1.5 \pi$

Preference for nonmaximal θ_{23} but octant flips with hierarchy

LBL Acc + Solar + KL + SBL Reactors + SK Atm

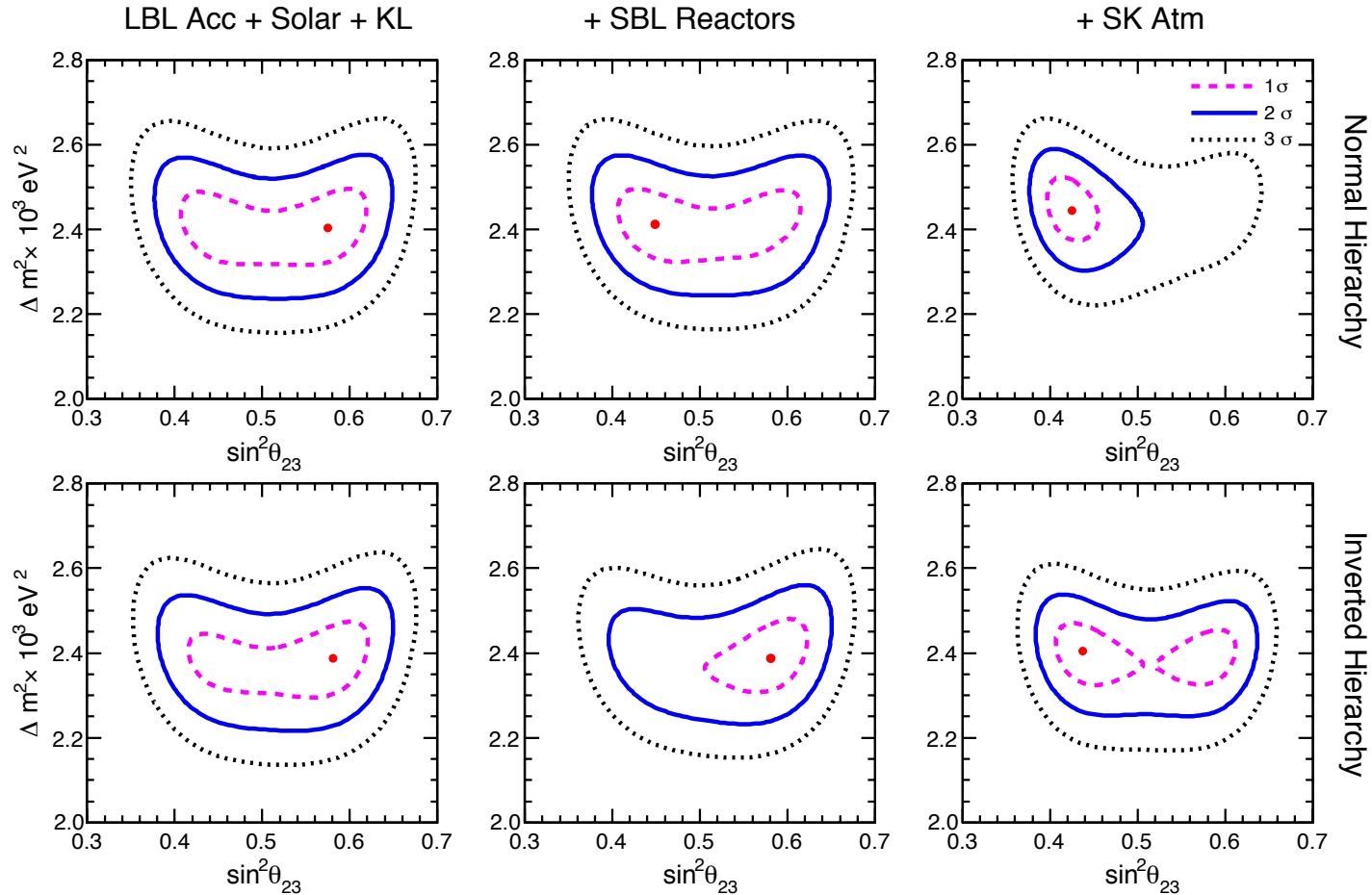


Some effects on the $\nu_\mu \rightarrow \nu_\tau$ dominant parameters ($\Delta m^2, \theta_{23}$)

More preference for $\delta \sim 1.4\pi$ and $1 < \delta/\pi < 2$ (i.e., $\sin\delta < 0$)

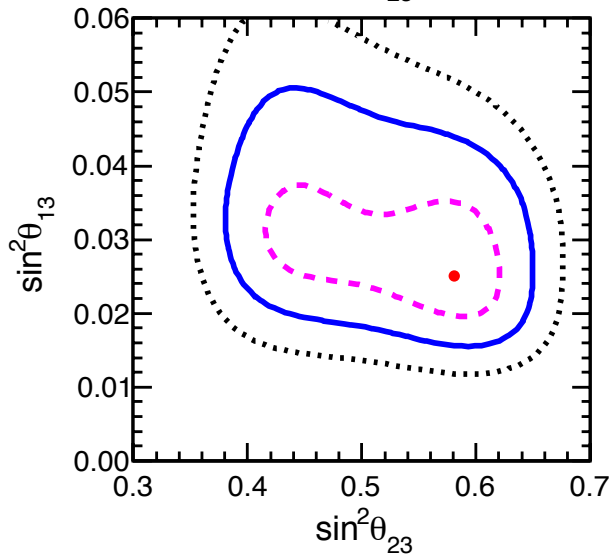
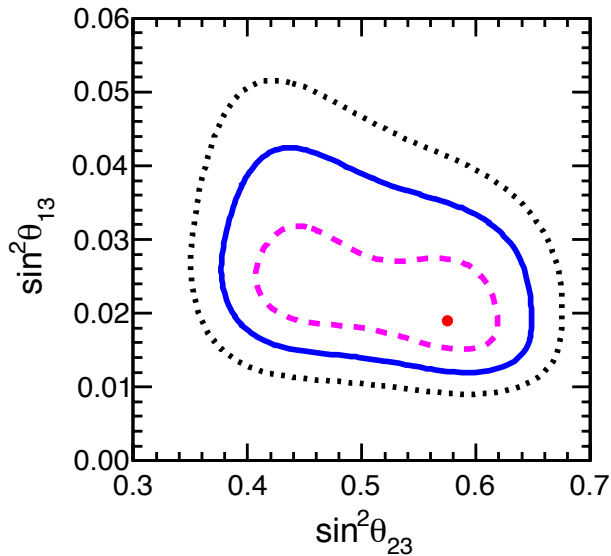
Some preference for nonmaximal θ_{23} and for 1st octant, but weaker in IH

Interpretation of θ_{23} octant “flip” ...



... easier by looking at $(\theta_{23}, \theta_{13})$ correlations

LBL Acc + Solar + KL



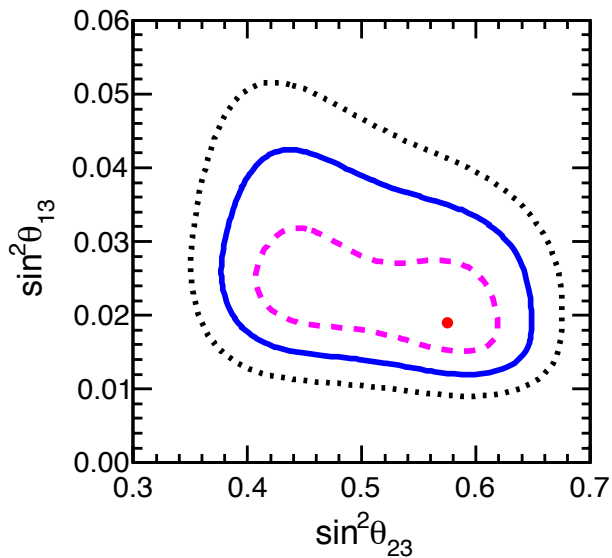
MINOS disappearance prefers nonmaximal mixing (and wins over T2K preference for \sim maximal) \rightarrow two degenerate minima for θ_{23}

T2K + MINOS appearance anticorrelate the minima with θ_{13} : the higher θ_{23} , the lower θ_{13} [appearance amplitude $\sim \sin^2\theta_{23}\sin^2(2\theta_{13})$]

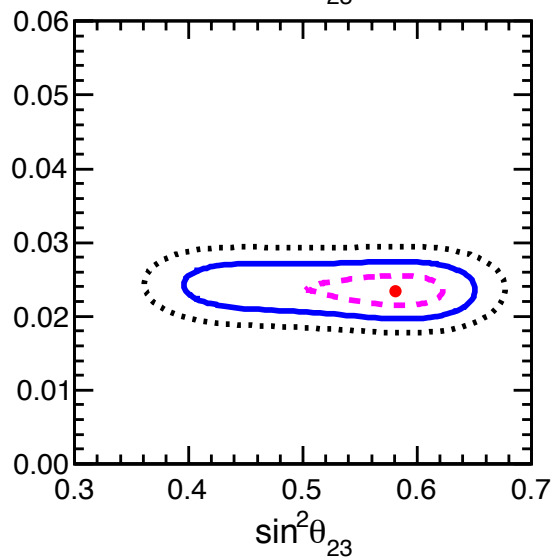
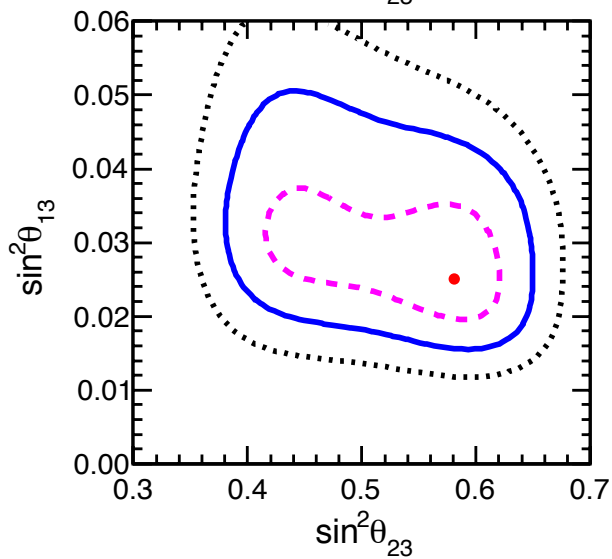
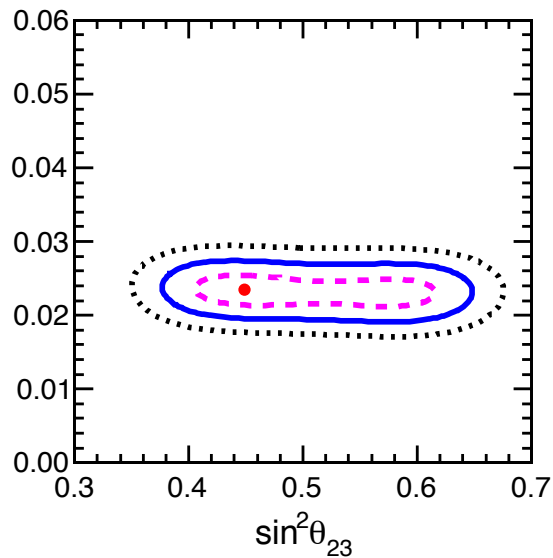
But T2K appearance is “strong”: both minima would be at $\sin^2\theta_{13}$ higher than suggested by Solar + KL (~ 0.02) in both hierarchies, and especially in IH

In the combination, Solar + KL data lift the degeneracy and prefer the second octant solution at lower $\sin^2\theta_{13}$

LBL Acc + Solar + KL

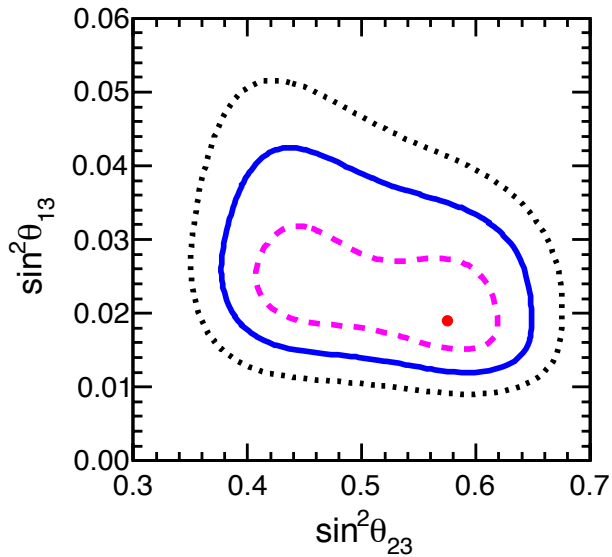


+ SBL Reactors

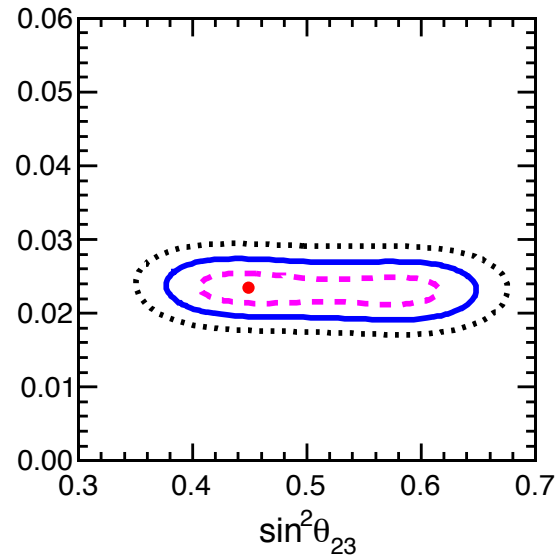


Reactor data prefer $\sin^2\theta_{13} \sim 0.023$, slightly higher than Solar+KL: enough to flip the octant in NH, but not enough in IH.

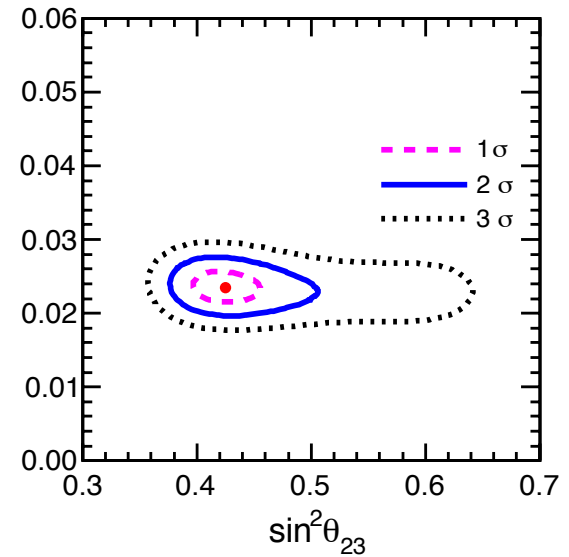
LBL Acc + Solar + KL



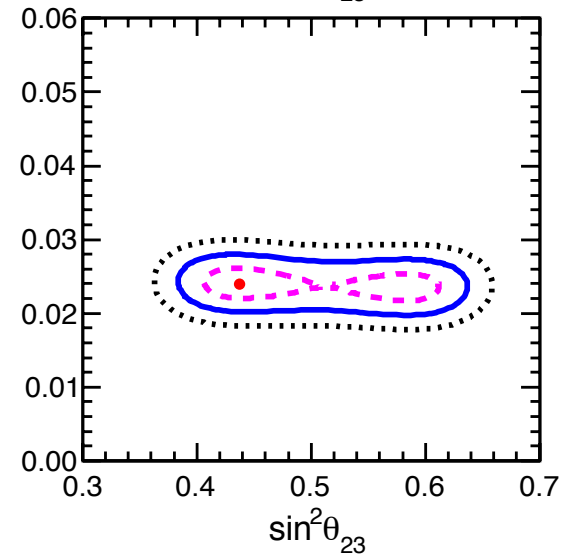
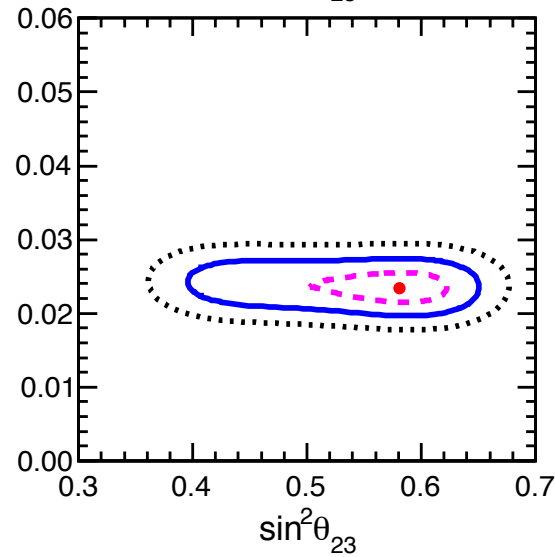
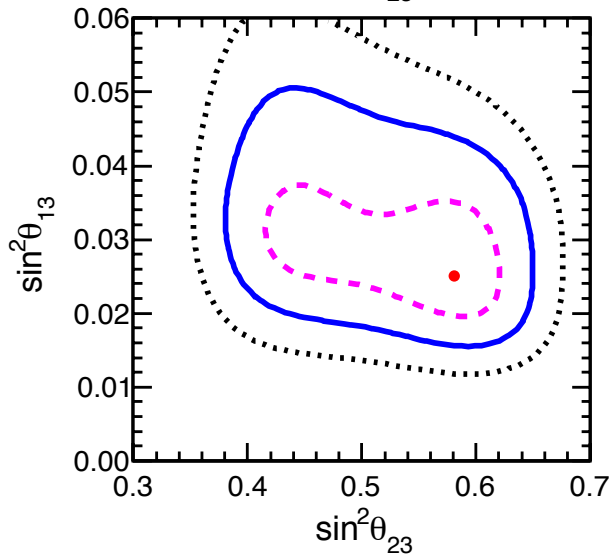
+ SBL Reactors



+ SK Atm



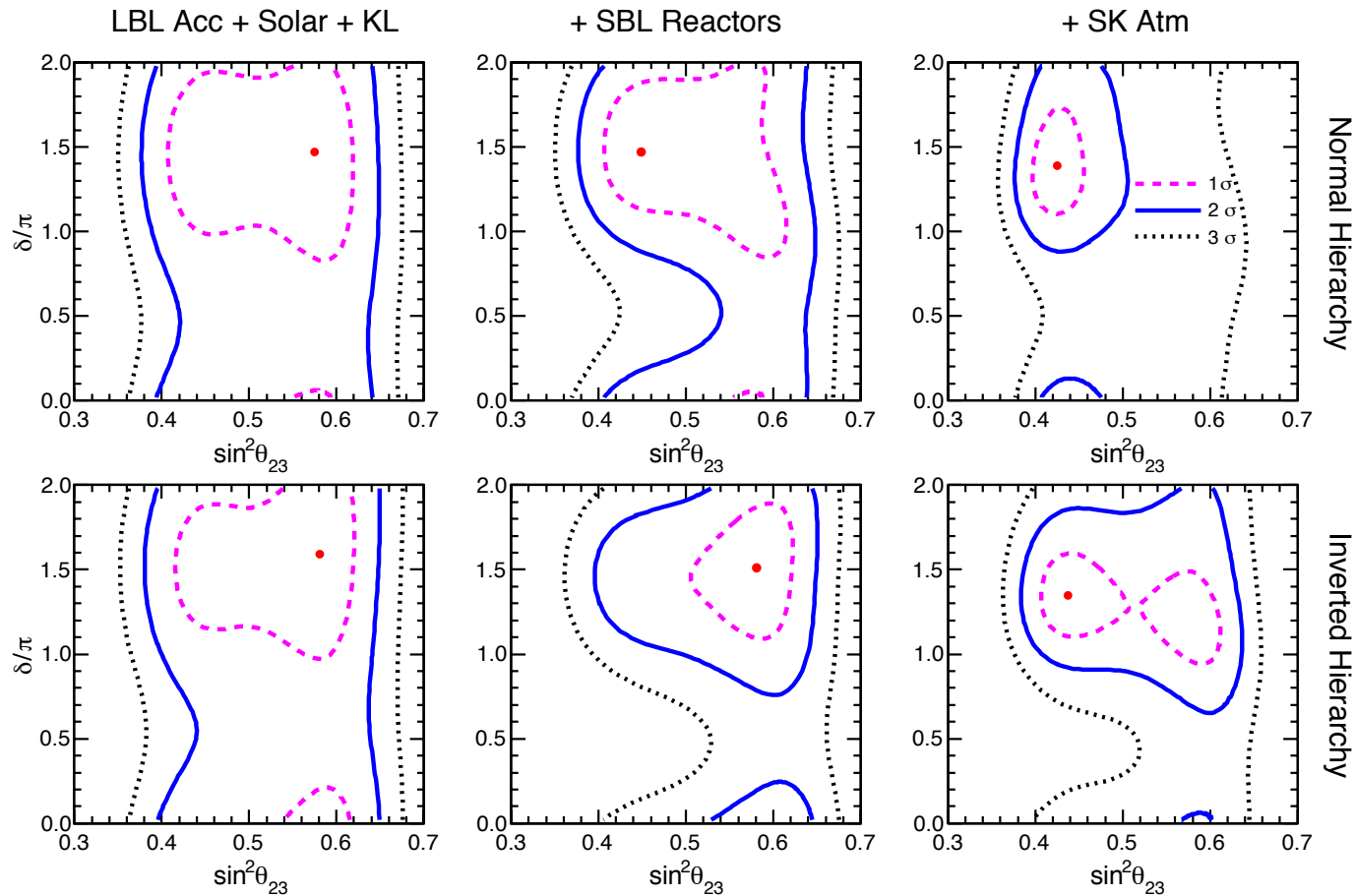
Normal Hierarchy



Inverted Hierarchy

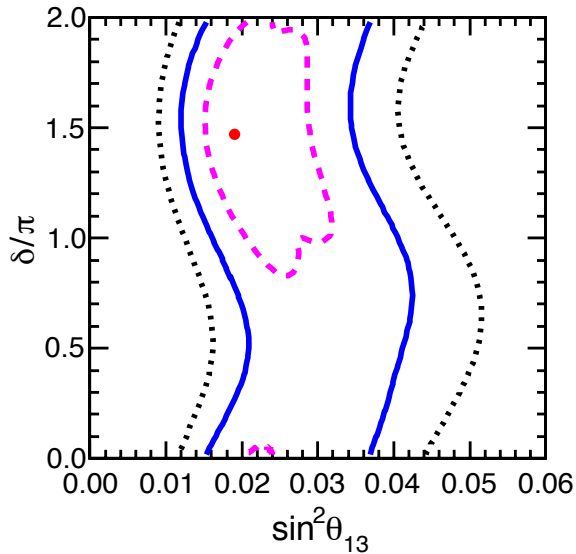
SK atm: We continue to find an overall preference of atmospheric data for the first octant – which currently wins over other data.

Interpretation of $\delta \sim 1.4 \pi$ preference ...

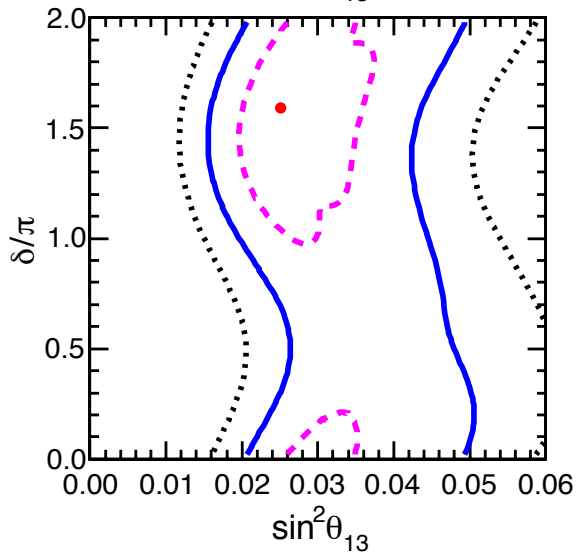


... easier by looking at (δ, θ_{13}) correlations

LBL Acc + Solar + KL

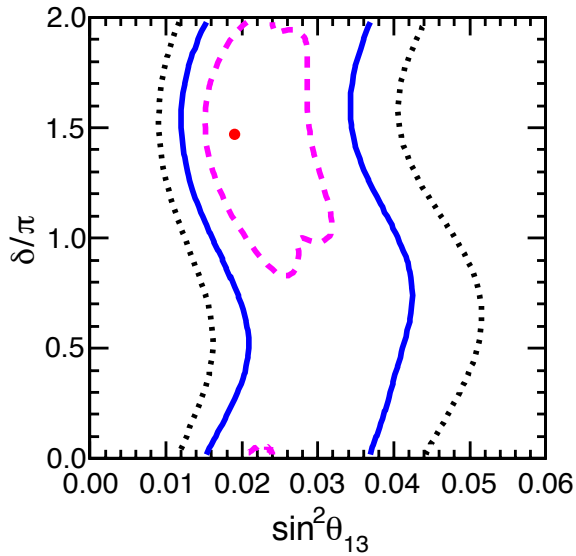


For the relatively “low” value $\sin^2\theta_{13} \sim 0.02$ preferred by Solar + KL data, appearance signal in T2K maximized by subleading CP-odd term for $\sin\delta < 0$ [i.e., $1 < \delta/\pi < 2$]

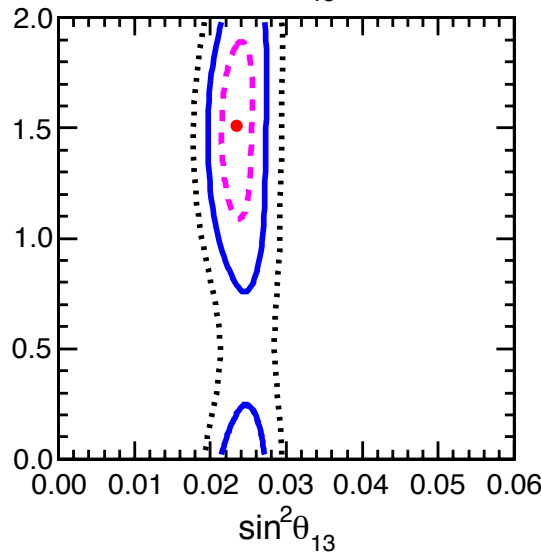
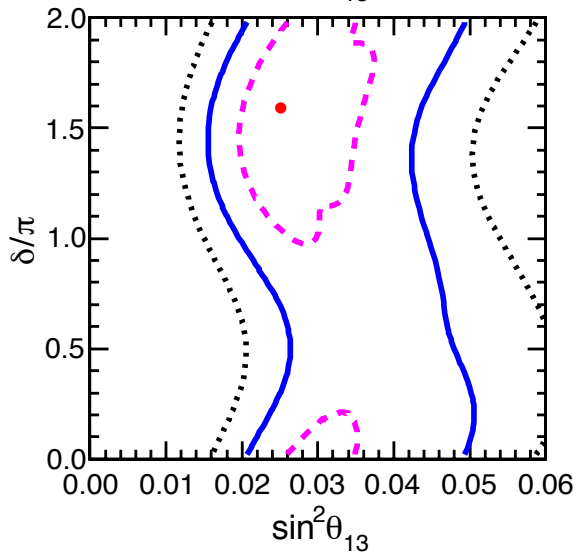
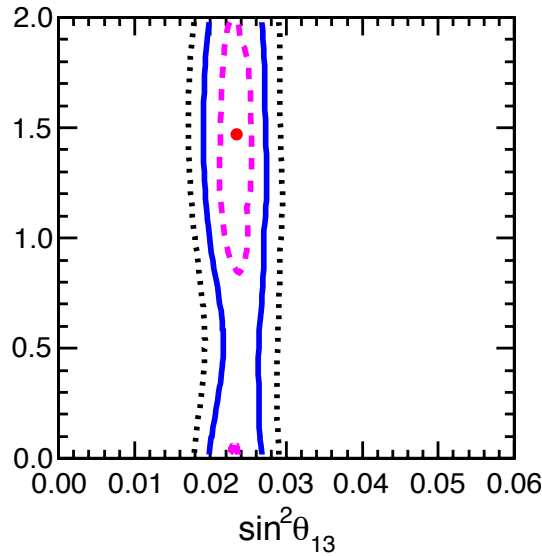


Best agreement with “strong” T2K appear. signal in the middle of the range, $\delta/\pi \sim 1.5$ irrespective of hierarchy

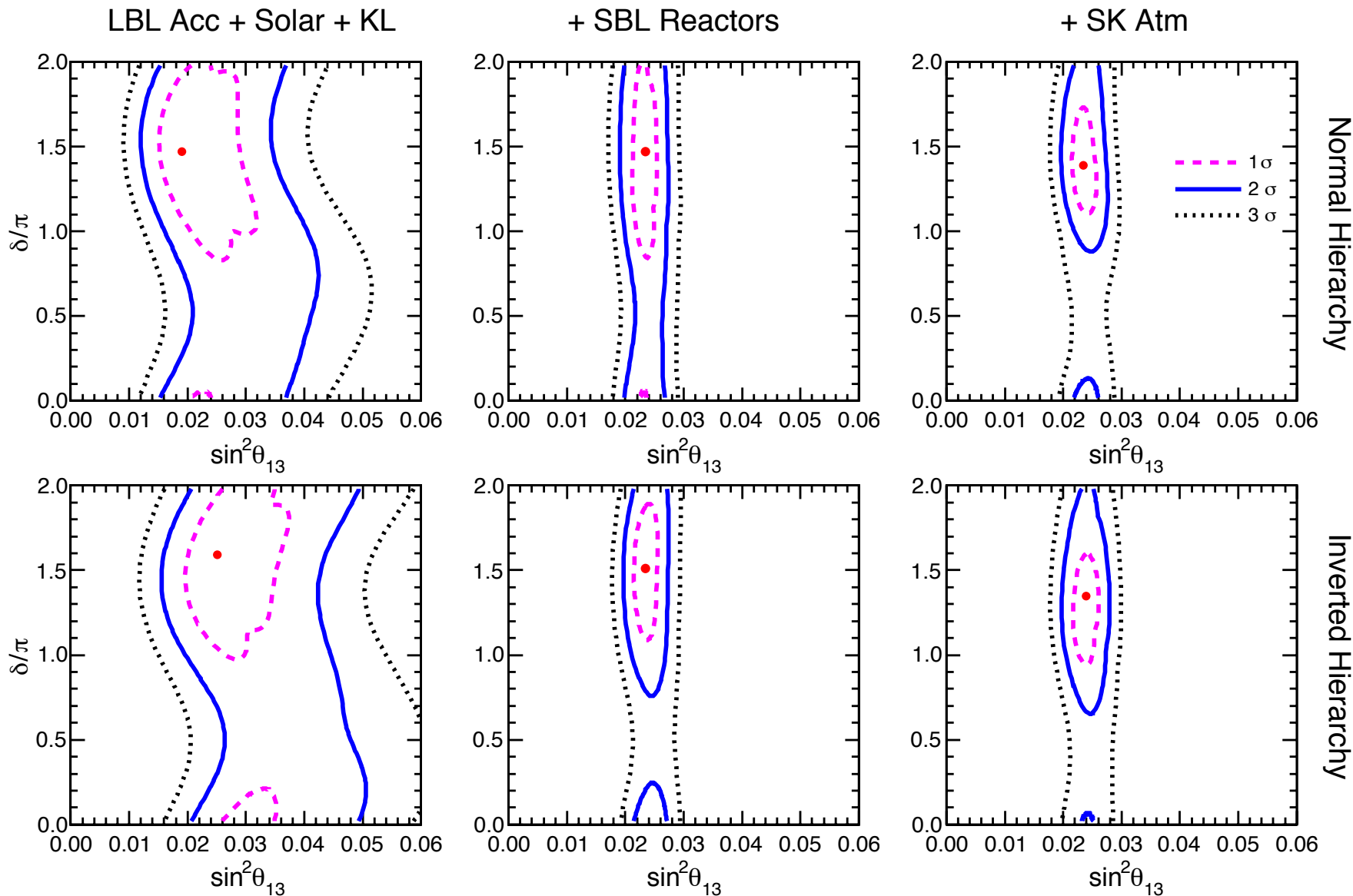
LBL Acc + Solar + KL



+ SBL Reactors



Reactor data shrink the band around $\sin^2\theta_{13} \sim 0.023$, higher than Solar+SK but still on the leftmost side of the band: preference for $\delta/\pi \sim 1.5$ persists



SK atm: We continue to find an overall preference for $\delta/\pi \sim 1$ (with $\delta/\pi \sim 0$ disfavored). In combination, $\delta/\pi \sim 1.4$ and $\sin\delta < 0$ favored.

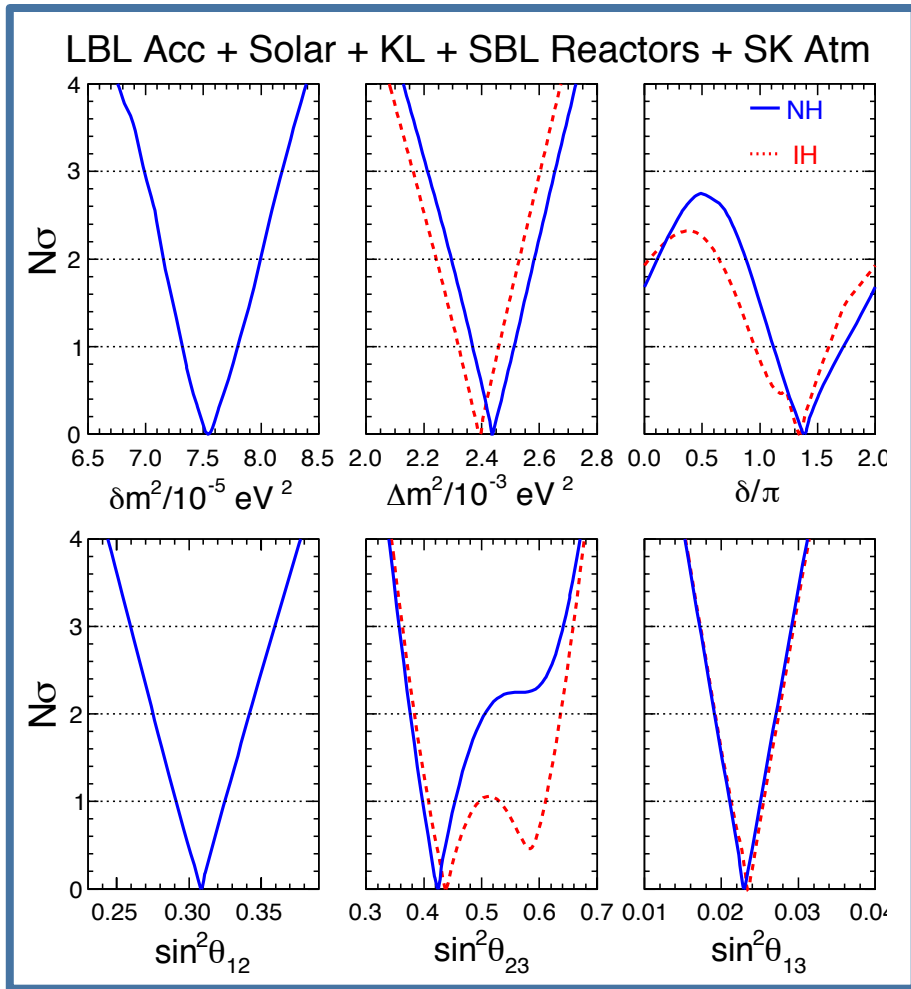
What about NH vs IH?

Figure of merit: $\Delta\chi^2 = \chi^2_{\min}(\text{NH}) - \chi^2_{\min}(\text{IH})$

LBL Acc + Solar + KL	:	$\Delta\chi^2 = +1.3$
LBL Acc + Solar + KL + SBL Reactor	:	$\Delta\chi^2 = +1.4$
LBL Acc + Solar + KL + SBL Reactor + SK Atm.	:	$\Delta\chi^2 = -0.3$

No significant sensitivity yet.

Summary:



Thank you for your attention.